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Final Report

Adaptive Characterization of Scallop Populations Using High Resolution Optical Imaging Phase 2

submitted by

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Adaptive Characterization of Scallop Populations Using High Resolution Optical Imaging

Phase 2

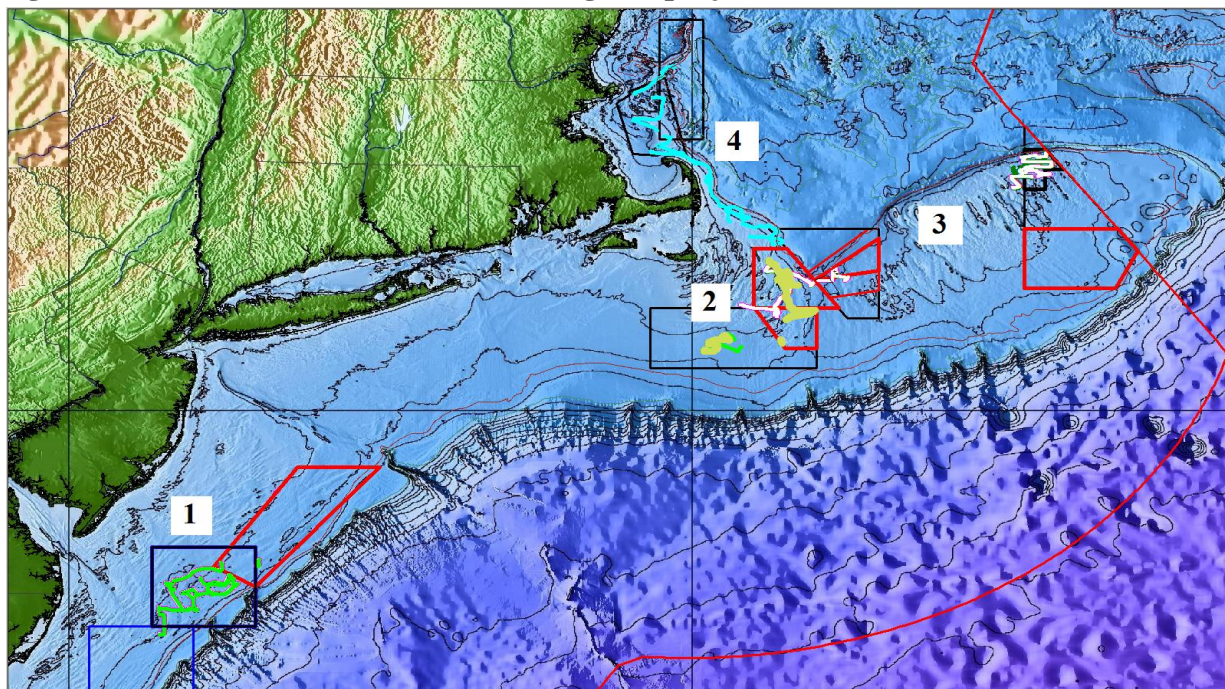
1. Abstract

Four cruises were conducted during July and August 2007 with the New Bedford commercial scallop vessel F/V Kathy Marie towing the habitat mapping camera system, HABCAM, and variety of acoustic sonar instruments. Over 3 million high resolution digital images (1280x 1024) were collected. The primary objective accomplished was conducting over 100 comparative transects during joint operations with the NOAA R/V Albatross IV during the annual NMFS Northeast Fishery Science Center (NEFSC) scallop dredge survey in several areas important to the scallop fishery (Elephant Trunk, Northern Edge HAPC, Closed Area 1, and western Great South Channel).

A secondary accomplishment included expanding the areal extent of substrate information collected during optical transects by the simultaneous use of various sonar instruments, including a vehicle mounted Imagenix 881a sidescan (675-1000 kHz) in operation during all cruises. Two cruises were conducted with a second towed vehicle, a McCartney FOCUS2, outfitted with a Kongsberg 3002 multibeam sonar (300 kHz) or an Applied Signal Technology Synthetic Aperture Sonar (SAS) in sidescan mode (175 kHz). A Teledyne BENTHOS C3D (200kHz) multibeam/sidescan sonar head was pole mounted off the vessel for the fourth cruise. All of these instruments produced data and imagery that allowed visualization of the substrate out to 100 meters or more on each side of the vessel trackline as the camera was being towed at the normal 4-5 knot speed revealing large and small substrate features.

A third objective, construction of the stereo camera system, encountered delays brought on by a significant shortfall in project funding (\$90,000 or 20%), the result of a low catch rates and price during the project funding trips. At this time the second towed vehicle with stereo cameras and the C3D sonar components has been completed and tank tested, including optical system calibration, with initial deployment scheduled for December 2008 on a cruise funded by NOS. All imagery and other associated data is available via <http://habcam.whoi.edu>

Figure 1. Cruise transects conducted during this project



2. Description of the problem addressed

This project focused on three areas relevant to the scallop fishery: 1) comparing scallop density estimates at the NEFSC dredge survey tow locations in specific resource areas using optical survey technology, 2) collection of substrate data at larger scales using acoustic technologies, in order to contribute to the knowledge base concerning both substrate and habitat for scallops and all other benthic species within the study areas, and 3) continued development of tools to access and visualize project data and information from derived products over the internet.

The first issue, accurate scallop density estimates of the Atlantic sea scallop resource, is of primary importance to scallop management, and thus to the sea scallop industry, particularly within access areas scheduled to open in the following year. In these areas biomass is very high, routinely measured in tens of millions of pounds, thus a small error in estimation equates to a large dollar amount. Underestimation results in unnecessary fleetwide economic losses for the year, while overestimation results in short term gains followed by longer term reductions and instability in catch rates, such as we saw in the initial opening of the Hudson Canyon area where fishing rates fell below costs in the third year of access. While there are procedural issues that need to be addressed within the Council system, they are primarily related to the timing of the survey and the scallop fishery year. The most important management need has been and will continue to be that of having accurate data to monitor scallop density, growth rates, and population in order to set the Total Allowable Catch (TAC) especially within the scallop access areas. The optical technologies utilized in this project are designed to assist in that process by increasing the area surveyed per day and removing variable dredge efficiency from the calculations, thus improving accuracy of the data available and minimizing survey time.

Dredge efficiency, that is the percentage of scallop retained by a dredge when towed over a scallop population, is known to have significant variability, particularly with regard to vessel towing speed, wire scope, substrate type, tow direction relative to bathymetry, and tow direction relative to tide and/or current. Although this variability is assumed to balance out over many tows, direct comparison with continuous optical transects allows for a greater understanding of dredge variability, and is intended to move us in toward greater precision. Collection and measurement of biological samples from dredge tows will remain a necessity in order to compare optically derived shell heights for accuracy in order to convert numbers and sizes to biomass.

Marine acoustic technologies such as sidescan and multibeam sonars have developed rapidly in the last decades vastly improving the speed and accuracy of collection of bathymetric and reflectance or backscatter data at various levels of resolution. These tools have enhanced our ability to rapidly visualize and understand the terrain and composition of seafloor areas at much larger spatial scales than can be achieved using optics alone. In 1994, with the establishment of the groundfish closure areas in New England, several areas of long term importance to the scallop fleet were removed from the fishery. Beginning in 1998 portions of these areas were reopened to the scallop fishery, however several areas with dense scallop populations remain closed to the fishery, ostensibly because they are considered special habitat areas for rebuilding populations of managed demersal species. These areas include the northern portion of Closed Area II, northern and southern areas within Closed Area I, and the central and western portions of Nantucket Lightship Closed Area. More recently the southern portion of the western side of the Great South Channel has been designated as another Habitat of Particular Concern (HAPC) by the New England Fishery Management Council, with specific management measures yet to be implemented.

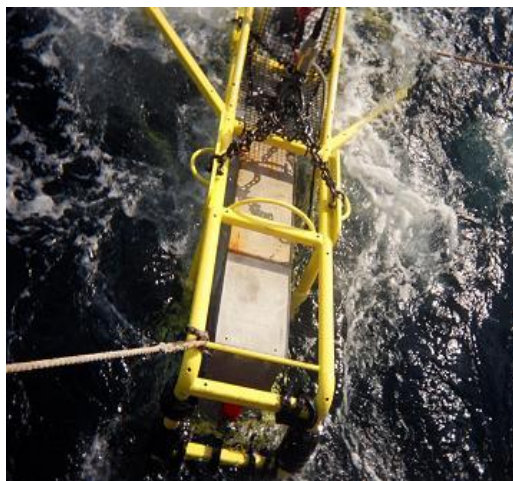
Most of these decisions were made using the sparse data available at the time. As a result we believe it is imperative to collect as much high resolution data as possible while conducting the camera transects for biomass estimates particularly within these areas. Collecting additional data from a variety of sonar instruments during HABCAM optical transects allows comparison of several technologies in order to aid selection of those with the greatest utility to both industry and regulatory needs. The simultaneous use of both optical and acoustic technology serves to save vessel and scientific crew expenses, and allows for direct comparison of data from different sources with a spatial precision not easily accomplished on cruises conducted at different times.

The third problem addressed is to continue to improve access to all project data via the internet. Over time the approaches that worked well for the initially small amount of data and imagery have been challenged by the rapidly increasing volume collected. As the data collection methods improve and as other sources of data are collected, each year we are generating as much data as in all previous years combined. As a result better methods for data access and visualization are needed in order to provide and present more easily assimilated information.

2.1 Background on previous use of HABCAM instrument

In 2002 the Northeast Consortium of Sea Grant institutions funded initial development of the camera and vehicle culminating in a four hour transect in the western Great South Channel conducted from WHOI R/V Oceanus in March 2003. Basic components of the instrument package, consisting of a networked high dynamic range digital camera, two machine vision strobes for lighting, a CTD, altimeter, compass, ADCP, and an Imagenix 881a sonar, performed as designed, however light levels were below those necessary for first quality imagery. About 11,000 images were obtained.

In 2005 funding from the NEFMC Scallop RSA program (NOAA NA05NMF4540009) allowed the HABCAM group to make major modifications to the existing towed vehicle frame, double the strobed lighting to 4 40w units, and outfit the New Bedford scallop vessel Kathy Marie with data acquisition computers and storage drives, an A-Frame and a refurbished WHOI NOMAD winch with 3 fiber, 3 conductor (120V), 0.68" armored cable suitable for conducting independent camera transects on the scallop grounds. Approximately 750,000 images were obtained during three data collection trips conducted November 2005 to February 2006. Significant progress was made in developing image processing algorithms including lightfield removal and color correction (Vine). Progress was made in development of segmentation algorithms to extract targets (scallops and other taxa) from the color processed imagery (Gallager). In 2006 additional funding was obtained from scallop RSA (NA06NMF4540264) producing over 2 million images including the first two comparative tows conducted with NOAA R/V Albatross IV.



Operationally the camera system is towed at ~4-5 knots (~2m / sec) and acquires images at a frame rate of ~5 per second with ~50% overlap, resulting in a track of about 100 nautical miles (170km) per 24 hour day. The resulting imagery may then be subsampled at any interval or combined into a continuous ribbon of overlapping images or mosaic for determining spatial statistics at various scales.

2.2 Goals and objectives of this project as stated in the proposal

The two primary goals of this project were to: 1) compare scallop density estimates using optical methods with the NOAA R/V Albatross IV dredge survey results on smooth bottom, such as in the Elephant Trunk, and on more variable substrates such as the Northern Edge, Closed Area 1, and the western side of the Great South Channel, and 2) refine and expand the capabilities of the towed vehicle, by increasing the areal coverage of the data generated while conducting the optical transects using by sonars, and by increasing the precision of the dimensional analysis of the scallop shells and other benthic targets by developing a stereo camera system.

These goals were to be accomplished by achieving four objectives :

Objective 1. Joint ship operations with the NOAA R/V Albatross IV - MidAtlantic

Optical transects were to be conducted at the location of over 100 R/V Albatross IV tows made during the 2007 scallop survey to allow comparison of sampling methods and the effect on population statistics. This first objective was to meet the Albatross on Leg 1 in the MidAtlantic Elephant Trunk, an area with smooth bottom, and conduct approximately 50 comparison tows.

Objective 2. Joint ship operations with the NOAA R/V Albatross IV- Georges Bank

Here Kathy Marie was to meet the Albatross on Leg 2 of the 2007 NEFSC scallop survey, (Northern Edge HAPC, Closed Area 2, Closed Area 1, and western Great South Channel), and collect image data at the location of survey tows in areas of more variable substrate and terrain.

Objective 3. Continue to develop camera capabilities

This third objective was to build a second vehicle and stereo camera system. Stereo imaging was seen as the most effective method of deriving accurate measurements of imaged taxa, with the primary interest of scallop shell height for biomass calculations. It was foreseen that having the height (z) component would be a benefit to segmentation algorithms used to identify targets within the imagery. Additionally a spectrophotometer (Integrating Sphere, HOBI Labs) was planned to give realtime water absorption characteristics to assist in color correction of the imagery, and the remaining tasks in the image processing chain, segmentation and mosaics.

Objective 4. Conduct sonar tows simultaneously with the camera survey transects

The proposal included a contract with a commercial sonar contractor, in order to assess the utility and operational practicality of obtaining acoustic data over a wider swath width using various sonar instruments simultaneously with the camera transects.

2.3 Expected products from this project

The goals and objectives above were developed in order to produce the following products:

Comparison of results of paired transects and estimates of dredge efficiency

Acoustic sonar data and imagery for the areas where optical transects were conducted

Improvements to image processing: color correction, segmentation, and mosaics

Improved access to data and data products via the internet

All imagery and associated data (GPS time, latitude / longitude, altitude, depth, tow direction, vessel speed, conductivity, and temperature) were to be available via <http://habcam.whoi.edu>.

3.0 Description of approach and methods

3.1 Conducting comparative tows with NOAA Fisheries R/V Albatross IV

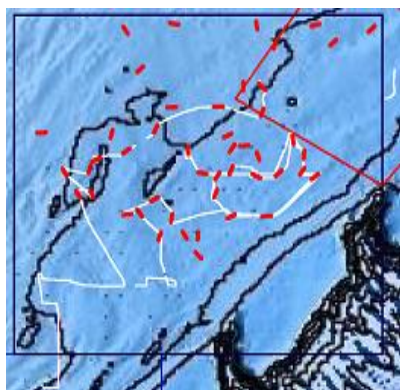
Data collection cruises were scheduled to conduct joint operations with NOAA RV Albatross IV while the vessel was in specific scallop resource areas, including the Elephant Trunk, NLSCLA, Closed Area 2 HAPC, Closed Area 1, and open area of the western Great South Channel.

A ship to ship wide area protocol (SWAP) communication network was established with the installation of FM transmitters and antennae on both R/V Albatross IV and F/V Kathy Marie. This system, developed at WHOI for conducting other joint operations, allowed the watch chief on the Albatross IV to place data files on a laptop which broadcast them to a receiver on the Kathy Marie. Though somewhat dependent on weather, the network operated as planned out to a vessel separation distance of about 5 nautical miles. An added benefit was that the system was interruption tolerant, i.e. capable of storing queued data until communications were reestablished again as the vessels came back within range.

Although catch and size data from the scallop survey was provided by the NEFSC Survey Branch using the SWAP network, a Letter of Acknowledgement (LOA) for Scientific Research Activity was obtained from NOAA Fisheries Northeast Regional Office to conduct short sampling tows for comparison with the optically derived sizes of the imaged scallops. This was an important element in the areas not open to fishing, and in areas where the NEFSC survey tows were not conducted.

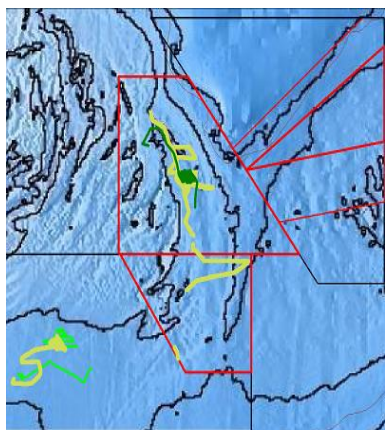
Synopsis of project cruises

Comparative tows in the MidAtlantic

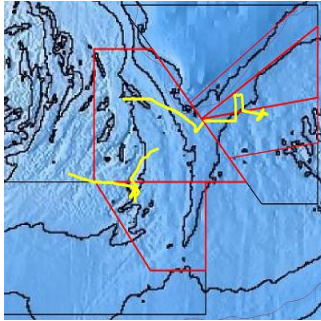


12-18 June 2007, Elephant Trunk. F/V Kathy Marie conducted joint operations with NOAA RV Albatross IV duplicating 34 of the 53 NEFSC survey tows concentrating on the high scallop density areas. Additional transects were made at 11 strata-tow locations before the NOAA vessel arrived in the area. An additional 140 nm of images were collected in between the NEFSC survey tow locations. Two Imagenix 881a sonar heads were mounted on the forward portion of the camera sled and operated in sidescan mode at 675-1000 kHz, each looking 50 meters out to the side. The portside instrument failed during the initial transect.

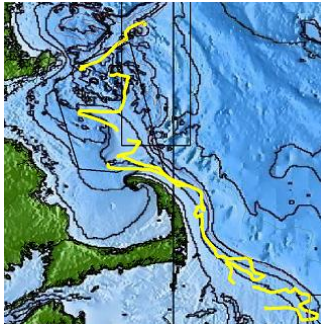
Comparative tows in New England waters



24-28 June 2007, G. South Channel, Nantucket Lightship. F/V Kathy Marie sailed south along the western side of the Great South Channel to an area south and west of the scallop fishing area within the NLSCLA, near the Andrea Doria, in order to meet the NOAA R/V Albatross IV. Kathryn Ford and Steve Foss, Massachusetts Division of Marine Fisheries, with the McCartney FOCUS2 vehicle and Kongsberg 3002 multibeam sonar were shipped. This area had been identified as having a dense set of scallop by previous Albatross scallop survey tows, and was specifically selected as it was not open to scallop or groundfish vessels with bottom gears, thus not subjected to the scientifically confounding effects of unknown amounts of fishing.



1 - 6 August 2007, Northern Edge HAPC, Closed Area 1, WGSC. Kathryn Ford, the DMF FOCUS2 vehicle, and the Applied Signal Technology sonar group shipped with F/V Kathy Marie and met the NOAA R/V Albatross IV in the Closed Area 2 HAPC as she crossed the International Court of Justice boundary line. 138 nm of sonar data was collected, 85 in conjunction with optical imagery. An additional 110 nm of optical transects were made between stations. 11 NEFSC tows were duplicated and 42 were made through the strata tow location before Albatross IV arrived.



28 August-1 September 2007, Outer Cape Cod, SBNMS, Jeffreys Kathy Marie steamed southeast from Nantucket Sound to conduct imaging transects at the site of the NEFSC survey tows from the northwest corner of Closed Area 1 along outer Cape Cod to Truro. Optical transects were made at 34 NEFSC tow locations along with 99 nm of additional acoustic and optical imagery transiting between stations. Kathy Marie then continued further north across Stellwagen Bank to Jeffreys Ledge, areas traditionally fished by the scallop fleet, where additional imagery and C3D data totaling 80nm were obtained.

3.2 Design, construction, and calibration of the stereo camera system

The HABCAM vehicle design has undergone three iterations of development until the current configuration was produced. Key elements were stability while under tow, and providing enough light to produce good color images, while not producing backscatter from suspended particles in the water. The current configuration, a central housing (7" diameter x 30" high) containing all electronic components, including a UNIQ 1830C high dynamic range CCD camera, surrounded by 4 equally spaced 40 watt strobes (Machine Vision 5002), was used as the starting point for the design of the stereo camera test vehicle. A second consideration was to make the new vehicle as small and light as possible given the fixed configuration of the camera and lighting, for two reasons. The first was to be able to deploy the camera on smaller vessels, and the second was in order to conduct experiments with decoupling the vehicle from vessel heave due to wave height over 6' by having a nearly neutral mass trail behind an intermediate weight or "clump". With this in mind it was decided to separate the stereo cameras from the remainder of the electronics, allowing the six housings to be contained in a frame that was only 16" high. A third consideration was to allow the integration of a Teledyne BENTHOS C3D (48V, 200 kHz), a combined multibeam / sidescan sonar system.

3.3 Integration of multiple acoustic sonar instruments during optical survey transects

The first consideration in expanding the data collected was the time synchronization of all data collection computers by broadcasting the GPS time signal throughout the shipboard network. Several synchronization software packages were tried. We are currently using Tardis and Beagle.

3.4. Improving color correction, segmentation, and mosaics

Over the course of towing the camera system for 18 months it became apparent that the characteristics of seawater were quite variable presenting significant challenges to color correction. An algorithm that worked well one in area did not produce satisfactory results elsewhere. It is well known that plankton densities vary widely with season, and from our own experience that water clarity was vastly improved in the winter months. However it is precisely during those winter months that the sea state is routinely greater than the 2 meter altitude off bottom where the camera must be flown to obtain adequate light for good color in the imagery.

Winter weather patterns present another problem as well, with the lows coming through on 2 and 3 day cycles, and require that the boat and science crew remain on standby until the winds begin to slack, tying up both the boat and personnel from other activities. As well it is difficult to plan trips longer than a day or two increasing the proportion of fuel spent on steaming to the transect locations and radically lowering the amount of imagery that may be obtained on a fixed cruise budget. Summer imaging cruises have the benefit of lengthy periods of calm sea conditions but include the necessity of overcoming the effect of particles in the water that make it difficult to obtain excellent color corrected imagery.

At the same time we have noted major changes in water quality (with regard to color correction) over very short spatial scales (10 and 100s of meters) in all seasons, particularly in the areas of greatest interest, i.e. in the vicinity of the persistent frontal boundaries. Thus it was seen as necessary to obtain realtime data on the light absorption characteristics of the water in order to adjust the color correction algorithm on the fly, adapting to different conditions as they occur.

To obtain the needed data we planned to purchase an integrating spherical absorption photometer (I-Sphere, HOBI Labs) that appeared to adequately measure the sum of light transmittance at all frequencies and output data to integrate into the color correction algorithms.

Segmentation

Our most challenging problem in image processing by far is segmentation of foreground targets from background sediment. We have taken the approach described in Gallager et al (2005) and Howland et al (2006), images are acquired at 5Hz and processed in real-time on the ship. Raw 16 bit Tiff images are light field corrected, color corrected, and converted to 24 bit jpegs. The jpegs are then segmented into regions of interest (ROI) removing the foreground targets from the background sediment. The ROIs are then subjected to feature extraction and classification into known categories such as flatfish, sponge, scallop, starfish, etc.

We are developing segmentation algorithms based on image texture, color and edge features that will operate efficiently in real-time following transmission of the images onto the deck of the ship using the approach being developed at the Los Alamos National laboratory (Prasad 2006, 2005).



Figure 15. Segmentation of image taken in Closed Area II, HAPC of nine scallops on a sandy bottom. Raw raster image (left), fully segmented vector image (center), vector image where polygons have been aggregated based on similar color and texture features. Note that the scallops have been successfully segmented.

Briefly, the image is first filtered through a Canny edge detection algorithm to extract edge pixel chains followed by the application of a constrained Delaunay triangulation of the edge contour set, which yields by application of a constrained triangles that tile the image without crossing edge contours. Each triangle is given a color based on pixel content with in it. Triangles are then

merged into polygons based on a set of rules such as proximity, continuity, color, etc. The resulting polygons are represented in the segmented image by a variety of targets (Fig. 15 above). The process essentially converts a raster image into a vector image with polygons in the vector image representing targets of interest. A variety of grouping filters or rules may be implemented during the triangle aggregation stage to achieve desired results. Characterization of sediment (sand, gravel, cobble, boulder) actually falls out of the segmentation process since the process of triangulation and development of polygons encompassing regions of similar texture and color provide a measure of surface area and grain size. Grain size is then mapped back onto a simplified substrate characterization scheme as that provided by Valentine et al (2005).

Classification of the segmented polygons begins with feature extraction followed by both unsupervised and supervised classification. Features currently being extracted include surface texture (entropy, energy, correlation, and homogeneity) and color (ratio of red, blue, green image planes). Morphological descriptors such as size, excentricity, ellipticity, Fourier descriptors, etc. are also used when the target of interest has a defined shape, but these are not useful features for low growing colonial forms such as tunicates, sponges and bryozoans. The features are then subjected to a principle components analysis to reduce dimensionality of the data set. The first three principle components are used as features in a Support Vector Machine classifier, which has been trained with manually classified image data from the image test sets.

Automated image mosaicing

The basic approach includes multiple control points in order to account for the variable look angle caused by roll, pitch and yaw of the HABCAM vehicle as it is towed. The mosaic strip of *Didemnum* (Fig 23b, Rzhhanov, CCOM, UNH) illustrates both the progress and the difficulties in registering images to each other, and balancing the color obtained from the camera CCD.

3.5 Improving methods of providing internet access to project data and data products

Our solution to this issue was to make HABCAM cruise tracks and imagery accessible using multiple methods. These include MapServer, Google Earth, Open Layers, and the WHOI Data Viewer with each application having specific strengths.

4. Results

Over three million images were collected during 4 cruises from June to September 2007. and are online at the HABCAM website <http://habcam.whoi.edu>. All imagery from previous and ongoing efforts along with highlights, and all related data products are accessible.

Overall Kathy Marie conducted 167 passes through the 1 nm circle around the strata-tow locations where the Albatross IV was to set the survey dredge. Of the 109 separate NEFSC sites imaged, 58 were imaged with multiple passes, and 74 specific tracks were imaged using the start and stop points.

Figure 7. Table 1. Summary table of bottom imagery collected during this project

trip #	cruise	CLA I	CLA II	ET	NLS	SBNMS	WGSC	OpenArea	total
12	KM_20070613	0	0	727,911	0	0	0	47,447	775,358
13	KM_20070725	0	0	0	274,506	0	356,099	2,742	633,347
14	KM_20070801	104,399	313,625	0	79,100	0	334,832	110,984	942,940
15	KM_20070828	28,973	0	0	0	335,433	74,670	434,997	874,073
								total images -->	3,225,718

Examination of the subset of comparative tows having the closest tracklines reveals wide variation in scallop density estimates between the dredge and optical survey methods implying

either patchiness at very small scales (10s of meters) or a wide range of dredge efficiencies. Shell height comparison were generally within 10mm and consistently higher implying a systematic measuring error, another source of potential difference in a biomass estimate based on shell size. Although the dredging process routinely breaks off the very thin sharp outer edges of the shells the differences noted are too large for that to have been the only explanation.

4.1 Comparison tows

MidAtlantic area

F/V Kathy Marie met the NOAA vessel in the Elephant Trunk, however mechanical issues caused changes in both vessel's arrival time on the fishing grounds. Two types of comparison tows were conducted in 29 tow locations. The first type occurred when the NEFSC tow had been completed, start and stop points were transferred either by the SWAP system or over the VHF, and Kathy Marie towed the HABCAM instrument between the points as closely as possible. In some cases multiple passes down the dredge tow path were made. The second type occurred when Kathy Marie was in the area with the camera before the NOAA vessel had conducted the dredge tow. This was caused in part because of the high catch rates and the deck processing time required by the NEFSC science crew. In these cases generally 2 nm of imagery was collected within the 1 nm diameter circle where the NEFSC tow was scheduled to occur and provided an independent estimate of scallop density in the area. At 9 Albatross stations both types of optical transects were conducted resulting in about 4 nm of imagery being collected in the 1 mile circle for each.

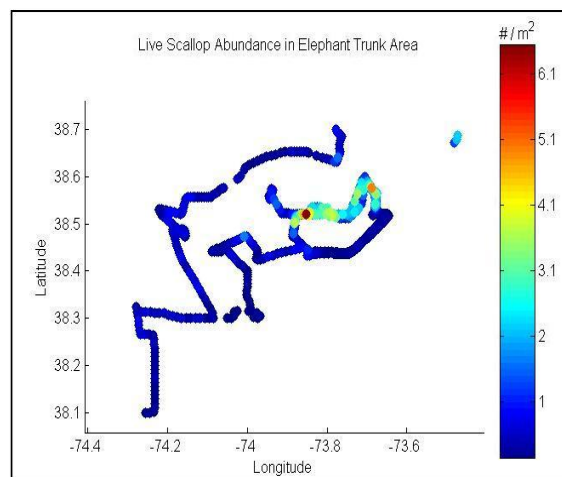
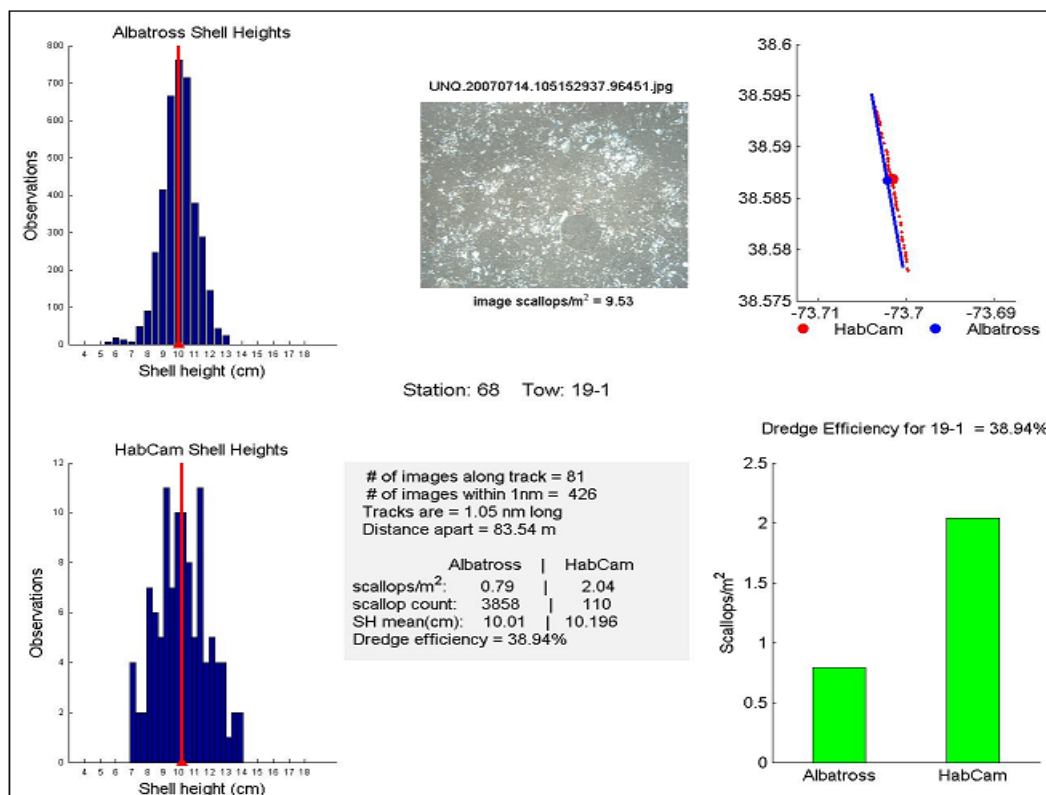


Figure 9. Example of graphical output for paired comparative tows (York)



Planning more comparative tows in the Hudson Canyon Access Area we steamed north, however the termination fitting connecting HABCAM to the towing wire failed while setting out and the camera sled plunged to the bottom. Fortunately we were in shallow sandy area. Grappling gears were fabricated by welding spare cutting bars. The camera sled was retrieved without significant damage, though one days planned data collection was lost. The wire was cut back, the fiber optic strands polished, and the fitting re-terminated in preparation for the second trip.

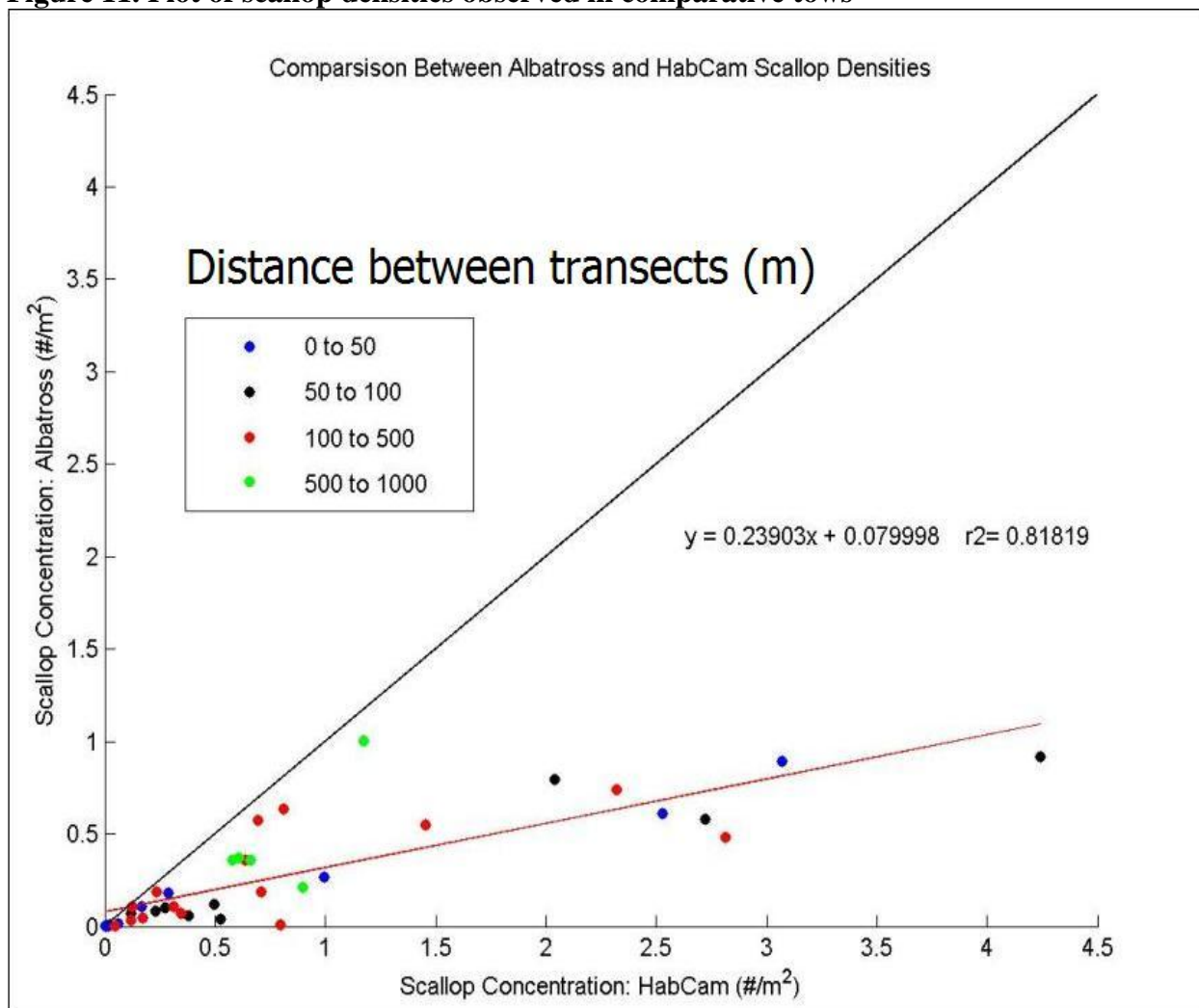
Northern areas

Additional scheduling issues were encountered with the fixed dates of availability for the sonar contractors and the flexible nature of the Albatross schedule based on catch rates. Both the AIS system and email communications between all parties enabled the vessels to meet up on time. About half the comparative tows were conducted while the two vessels were in the same vicinity, with the other half within a week of the NEFSC tows, not seen as significant in the closed area sites not accessible to the scallop fishery, or in open area locations where densities were low.

Figure 10. Table 2. Examples of tabular numerical data from comparative tows

area	station	tow	alba count	hab count	alba area	hab area	alba #/m^2	hab #/m^2	dredge_eff
ET	98	14-16	1688	17	4581	31	0.37	0.60	61
ET	96	14-4	1694	20	4748	34	0.36	0.58	62
ET	95	14-6	1010	17	4700	19	0.21	0.90	24
ET	81	18-1	840	16	4662	56	0.18	0.29	62
ET	55	18-10	520	9	4720	52	0.11	0.17	66
ET	51	18-11	880	41	4729	60	0.19	0.71	26
ET	53	18-12	492	14	4677	44	0.11	0.31	34
ET	49	18-14	318	21	4523	61	0.07	0.34	20
ET	52	18-15	394	11	4844	46	0.08	0.23	35
ET	47	18-17	1704	45	4767	65	0.36	0.66	54
ET	58	18-18	2976	57	4662	69	0.64	0.81	79
ET	48	18-2	480	10	4566	83	0.11	0.12	85
ET	59	18-8	1575	38	4413	62	0.36	0.64	56
ET	68	19-1	3858	110	4858	57	0.79	2.04	39
ET	70	19-10	2900	555	4744	217	0.61	2.53	24
ET	62	19-11	4423	943	4949	314	0.89	3.07	29
ET	61	19-17	4752	70	4724	60	1.01	1.17	86
ET	71	19-2	448	60	4471	209	0.10	0.27	37
ET	60	19-3	3410	602	4600	271	0.74	2.32	32
ET	66	19-6	4420	265	4801	61	0.92	4.24	22
ET	56	19-9	2559	79	4672	56	0.55	1.45	38
ET	38	22-5	1296	30	4878	59	0.27	0.56	48
NLS	263	47-25	1217	272	4600	273	0.26	1.00	27
WGSC	555	49-4	203	44	4547	269	0.04	0.17	26
WGSC	550	51-2	531	107	4523	207	0.12	0.50	24
WGSC	573	50-10	75	12	4677	204	0.02	0.06	27
HAPC	465	71-18	898	86	4724	396	0.19	0.24	80
HAPC	474	71-3	2621	264	4571	374	0.57	0.70	82

Figure 11. Plot of scallop densities observed in comparative tows



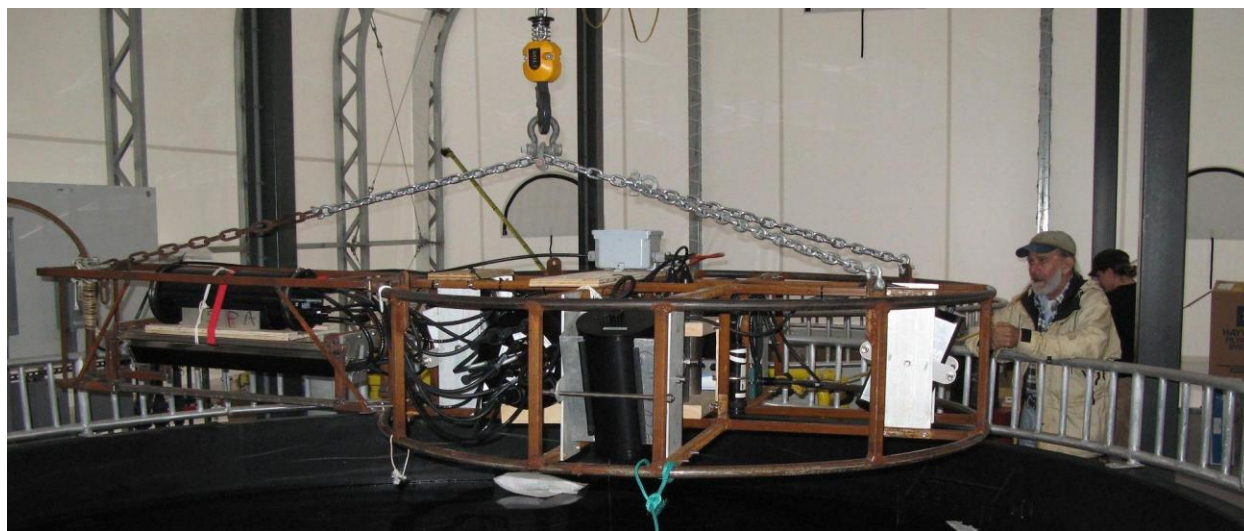
4.2 Design, construction, and calibration of the stereo camera system

Configuration of the electronic components

A circular testbed vehicle frame was constructed by welder D. Grosch using 1" OD round and square steel tubing, with modular spaced mounting holes for attaching various configurations of lighting and instrument packages. Mounting brackets to align and rigidly clamp the two camera housings were drafted using AutoCAD, precisely cut on a waterjet system, and the completed assembly bolted in the central bay of the frame. A second removable frame was constructed to conform to the requirements of the C3D sonar arrays and electronics bottle, and was bolted to the circular frame, then fitted with fins to provide directional stability. Skids were added to provide protection from inadvertent contact with the bottom while under tow. Final configuration will be dependent on results of the initial tow tests scheduled in early December 2008 on a cruise funded by Integrated Ocean Observing Systems, National Ocean Service (NOAA/IOOS/NOS).

Control software to manage the data flow from all sensors was developed by Jon Howland. The stereo tow body was powered up in the tank facility at WHOI in order to perform function checks, optical alignment, and focus, and initial calibration for lens distortion and aberration.

Figure 12. Stereo camera tow vehicle with integrated 200 kHz BENTHOS C3D sonar being calibrated in the HabCam test tank facility.



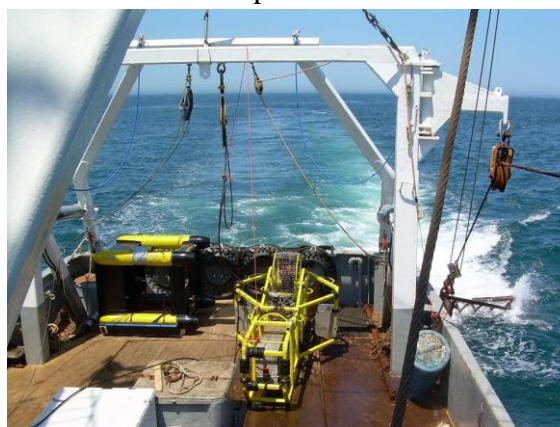
4.3 Acoustic sonar data in areas where optical transects were conducted

The scheduled sonar contractor, Crayton Fenn, of Innerspace Explorations, Seattle, Washington, was unable to meet the Kathy Marie cruise schedule because of an unexpected extension to a sonar contract in the Aleutians. Alternate arrangements had to be made.

Acoustic data was collected throughout all four cruises with an Imagenix 881a (675-1000 kHz) mounted on the HABCAM vehicle and oriented to starboard, producing a 50 meter swath width and total track length of ~750 nm. A second 881a sonar head was mounted adjacent to the first and oriented to port, however failed during the first day of the first cruise and could not be replaced. On each of the last three trips an additional and different sonar was utilized. All data collected was reviewed with the acquisition software in order to make the screenshots displayed.

Due to fortunate timing Kathryn Ford of the Massachusetts Division of Marine Fisheries and their McCartney FOCUS2 vehicle and winch with a Kongsberg 3002 multibeam echo sounder (MBES) were able to accompany Kathy Marie on the second cruise. Electronics issues prevented collection of data along the western side of the Great South Channel, however were overcome by the time Kathy Marie met up with R/V Albatross IV in the Nantucket Lightship area. Data was collected in the area of joint tows and at the site of the Andrea Doria to provide a “hard” or known target for instrument calibration. Multibeam data was collected for approximately 50 nm in the area. The editing and viewing software license was not able to be purchased due to the funding shortfall. Unforeseen vessel deck configuration issues prevented simultaneous towing of both the camerasled and sonar vehicles.

After modifications were made to the deck to allow smooth shifting of vehicles during setting and retrieval, we sailed to the Northern Edge of Georges Bank, meeting NOAA R/V Albatross IV and conducted joint operations for a small number tows due in part to thick fog in the area. There were 12 individuals aboard Kathy Marie, including 8 from the science party.



The third cruise again included the MDMF FOCUS2 vehicle now with the Applied Signal Technology Synthetic Aperture Sonar (SAS) instrument. Because of the fragile nature of the FOCUS2 and the 5' Applied Signal sonar arrays, and the known presence of fixed strings of lobster gear in the area, sonar operations were scheduled for daylight only. On the second day the first attempt was made to tow both vehicles simultaneously. After a little practise setting and hauling the vehicles in sequence and learning the basics of towing and turning, the procedures became routine. The remainder of the trip was spent in Closed Area I and the western Great South Channel with both vehicles in the water during daylight and HABCAM only at night while running transects over the location of NEFSC scallop survey tows. Approximately 196 nm of optical imagery was acquired, and 138 nm (256 km) of acoustic data the latter implying an areal coverage of approximately 50 km². Persistent problems with the inertial navigation system prevented the full use of the synthetic aperture software, however the imagery in produced in sidescan mode (175 kHz) was exceptional (Figure 24).

The Applied Signal Technology (AST) programming team supplied our group with both the data collected and a data reader for their proprietary file structure that enabled us to review the waterfall imagery and the output. Further development of their file structure is ongoing.

Figure 14. Table 3. Approximate areal coverages

Trip #	HabCam	Imagenix	3002MB	AST SAS	C3D	jointly	notes:
1	186	186				0	
2	160	160	47			0	
3	196	196		138		85	
4	212	212			212	212	
~total nm	754	754	47	138	212	297	
~total km	1396	1396	87	256	393	550	
~swath m	1	50	400	200	200		C3D stbd only
~area km ²	1.4	70	35	51	79		

The fourth cruise included a pole mounted Teledyne BENTHOS C3D multibeam/sidescan sonar on the starboard side of F/V Kathy Marie. Data collection began outside Great Round Shoal with the trackline continuing southeast to the northwest corner of Closed Area 1, and then north along the east side of Cape Cod from Hyannis to Truro to complete the coverage of the NEFSC scallop survey tows. F/V Kathy Marie then continued across the gully north of Provincetown and across the northern end of Stellwagen Bank and southern Jeffreys Ledge, in areas traditionally fished by the scallop fleet. Overall approximately 212 nm (390 km) of multibeam bathymetry and backscatter were collected, however there was significant electrical interference with the sonar signal on the port side, either from the Kathy Marie's echo sounder or the mounting location, so only the starboard side of the swath is useful. Additionally the instrument package did not have an operational inertial navigation electronics package and therefore is not of navigational quality.

The use of the various sonars allowed direct comparison of their strengths. The Imagenix had been mounted forward on the HABCAM vehicle however used primarily in forward scanning mode. It was not until the cruises during this project that it was activated to look out to the side, presenting a good representation of bottom features even though at ~3 m altitude. The unplanned introduction to the advanced capabilities of the FOCUS2 vehicle and the two very different acoustic instruments, 3002 multibeam and AST sidescan, added greatly to the useful data generated for comparison with the optical imagery. The mechanics of towing a second vehicle became routine. However the outstanding results are tempered with the practical experience that the complexity and fragility of the vehicle and the many components of the acoustic sonar systems require a complement of expert technicians to ensure continued data collection.

4.4 Improving color correction, segmentation, and mosaics

Included in the instrument package planned for the next generation stereo camera system was to be a hyperspectral photometer (Integrating Sphere, HOBI LABS). This instrument was selected in order to measure the optical properties of the water in realtime during the imaging transects in order to improve color correction, and thus improve automated segmentation and mosaicing.

The instrument was not purchased because of the significant shortfall in funding (20% or ~\$90,000) brought on by the combination of low catch rates in the open area fishery, and the low dockside price at the time of the fund generating trips.

Despite not having accurate external data on the optical characteristics of the water to use Vine has continued exploration and development of color correction algorithms using only the data that is contained in the image that has resulted in increasing the number or percentage of successfully converted images. Earlier iterations routinely did not attempt to process those much above the sweet spot altitude of 1-3 meters. At this point they are all being processed though above 4 meters often not much can be seen.

Automated segmentation and classification

Table 4 shows the results of a classification run using five target categories. Percentage accuracy varied from 77% for seastars to 87% for razor clams. The high accuracy for razor clams is attributable to their very distinct elongated shape compared with the other categories.

Figure 16. Table 4. Comparison of manual and automated “target” segmentation results

		Manual					
		scallop	seastar	sediment	razor clam	other	% false positive
Automated	scallop	5984	8	240	43	193	8
	seastar	397	842	111	39	38	
	sediment	197	49	7839	31	2837	
	razor clam	54	129	62	1825	927	
	other	467	58	1132	138	15736	
% false negative		15					
	total manual	7009	1086	9384	2076	19731	
	% accuracy	84	77	83	87	79	

The key elements in Table 4 above are that, for scallops, there were 8% false positive or targets mis-classified as scallops and 15% false negatives or missed scallops and that the overall rate of correct classification was 84%. Different datasets from different areas will have different results.

4.5 Provide improved access to project data and data products via the internet

From the beginning making the data collected by the HABCAM imaging group available via the internet has been a central goal. While there are a number of capable software packages available, early efforts concentrated on the web-based mapping application MapServer with two reasons foremost. MapServer was developed as an open source software package that is a freely downloadable and customizable application for showing OGC-WMS compatible maps over the internet. It has a large and growing user base with rapid improvement of capabilities and while not having an initial purchase price or annual licensing fees, it did have a fairly steep learning curve. As well MapServer was browser based, meaning that anyone with an internet connection could see the HABCAM cruise tracklines, zoom in, and click on markers to view representative imagery or link into the full directories of all collected images.

The simple fact is however that no one application has all the capabilities that are needed or useful, each handles some aspects of data distribution and visualization better than the others. As time gone by four other methods of viewing HABCAM images and other cruise data have exhibited promise, are now linked and available via the <http://habcam.whoi.edu> website.

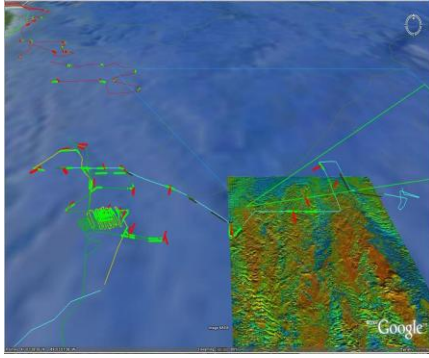
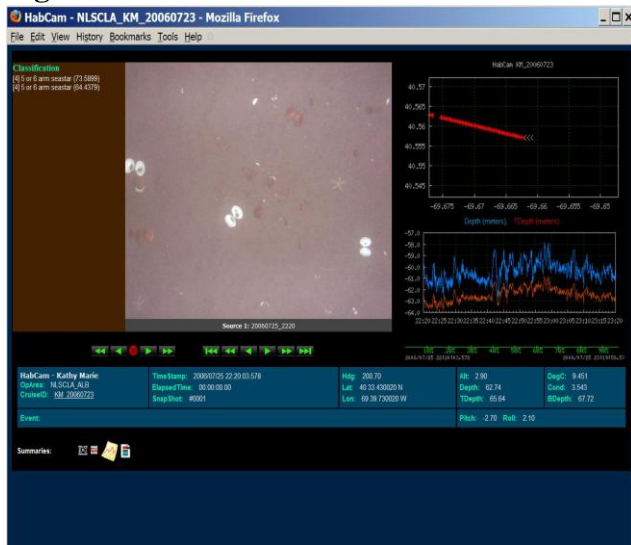


Figure 17. Google Earth

This application has developed a wide user base and gone through significant development with many advances contributed by users, however it must be downloaded and installed on the viewer's local machine implying a greater level of computer literacy than a browser based viewer. The application is not able to display 3 dimensional bathymetry but does have many advanced visualization capabilities useful to viewing our rapidly increasing volume of imagery. KML format files are now available for the cruises for this project.

Figure 18. WHOI Data Viewer



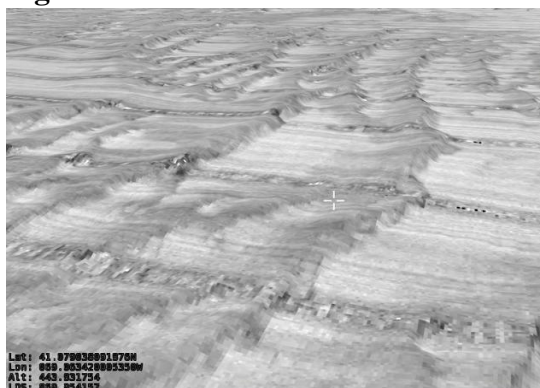
At the same time Steve Lerner has expanded and integrated the existing data viewing capabilities of browser based software used by WHOI for other marine applications. Along with access to the individual frames of the substrate imagery are several other unique features not available using other methods. This application plots the other data collected, i.e. temperature, depth etc, in an integrated window so that visual association can be made between species in the imagery and these other data. Additionally, there is the ability to scroll down a long mosaic strip in order the see the larger scale associations between imaged species and other features.

Figure 19. Open Layers



With the increasing use of web-based mapping services such as MapQuest and Google Maps technology based on tiles that speed up the rendering of repeated requests, another open source application Open Layers has emerged as a functional tool that, similar to MapServer, depends on OGC-WMS standards based interchange for data and can get the basics across in an intuitive straightforward manner.

Figure 20. OssimPlanet



OssimPlanet is a rapidly evolving open source project for accurate, high performance, 3D Geo-spatial visualization. It automatically intersects with DTED and/or SRTM elevation trees for topography and bathymetry and handles a wide range of commercial and government vector and raster file formats natively. Additionally, remote layers can be accessed over the web through OGC WMS interfaces.

<http://www.ossim.org/OSSIM/ossimPlanet.html>

4.6 Contribution to management

The primary accomplishment of this project is the results of the comparative tows. These results suggest that, while dredge efficiency varies widely between tows, the average efficiencies used by the NEFSC to convert from dredge contents to scallop density on the ground have been verified. Specifically the majority of the comparative tows fall within the range of 30 to 60 %, implying that calculated dredge efficiencies currently in use are substantiated by the HABCAM system for the areas of the dredge tows. However overall variability is quite high and there are examples significantly outside this envelope, with both higher and lower values, without any clear explanation of cause. It is expected also that the results of the followon effort in 2008, where more R/V Sharp tow locations were optically surveyed, will provide more insight.

Though only a small portion of the managed areas was imaged simultaneously with both optical and acoustic instruments, we believe that it is clear that the concept is sound, that a fishing vessel can conduct a seafloor imaging survey, simultaneously using several state of the art technologies, and produce results that go well beyond what is already known both quickly and inexpensively. The larger questions appear to be whether we will continue to invest in the collection of these types of high resolution data to provide insight into specific offshore areas, and, if so, will that data be put to use, or even considered, in what are primarily political decisions being made by the New England Fishery Management Council.

4.7 Opportunities for further work

The HABCAM imagery has begun to generate interest from researchers from outside of the scallop related fields. For example, the Stellwagen Bank Sanctuary staff is interested in the presence of marine debris, and included in that are category lost fishing gears.

In an entirely separate effort team member A York is well along in compiling a volume entitled HABCAM Benthic ID Guide: Georges Bank, Stellwagen Bank, and the Mid Atlantic Bight. To date this collection of images references 200 separate identification categories and totals 179 pages. For many individual species this in situ imagery is a welcome adjunct to line drawings or dessicated specimens. Especially interesting in the collection are examples of polymorphism of both color and shape, and the difference in color and patterning of some species between the in situ images and their appearance on deck.

5. Participating organizations

Woods Hole Oceanographic Institution, Woods Hole, Mass
Scott M. Gallagher, Jonathan Howland, Amber D. York

Advanced Habitat Imaging Consortium, N. Falmouth, Mass
Norman H. Vine, Richard Taylor, Monroe Tyler

Massachusetts Division of Marine Fisheries, Habitat Mapping Group, New Bedford
Kathryn Ford, Steve Foss

Applied Signal Technology, Sunnyvale, California
Andy Wilby, Randy Patton, Matthew Nelson, Shivesh Wangrungvichaisri

Center for Coastal Ocean Mapping (CCOM), University of New Hampshire, Durham, N.H.
Larry Mayer, Luciano Fonseca

Los Alamos National Laboratory, Los Alamos, N.M.
Lakshman Prasad, Sriram Swaminarayan
ISR-2, Space and Remote Sensing Sciences Group, International, Space and Response Division

F/V Kathy Marie, Arnie's Fisheries, Inc., New Bedford. Owner Arnold DeMello, Captain Paul Rosonina, Mate Jarry Schervo, Engineer Tony Melo, Joe Santos, Donald Rosonina.

Participating vessels: In addition to the F/V Kathy Marie, seven other commercial scallop fishing vessels participated in this project by generating the funding for conducting the work: Kayla Rose, New Bedford, Mass (Joe Corriea), Christian and Alexa, NYC (Art and Ken Ochse), Westport, New Bedford, (Edward Welch), Kathy and Jackie, New Bedford (Abel Arujo), Atlantic, NB (Peter Barcz), Santa Barbara, NB (Joe Viera), Cool Change, NB (Earl Chor)

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NEFMC Scallop RSA program grant (NA05NMF4540009) for funding further camera system development in 2005. This funding allowed the HABCAM system to become fully operational including A-Frame, winch, and major modifications to the towed vehicle.

NMFS Advanced Technology Working Group, Deborah Hart P.I., for providing additional funding for software development, data processing, a workstation, and server. The software specifically focused on color correction and segmentation of targets.

NEFMC Scallop RSA program grant (NA05NMF4540264) for funding camera cruises in 2006 allowing collection of over 2,000,000 images.

NEFSC Ecosystems Survey Branch, Russ Brown and the entire team, including NOAA R/V Albatross IV Captain and crew, and in particular Chief Scientists Stacy Rowe and Vic Nordahl.

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Kathryn Ford for her outstanding contribution of the MDMF FOCUS2 vehicle, the 3002 MBES system, and for the participation of the Applied Signal Technology group.

F/V Kathy Marie owner Arnold DeMello, Captain Paul Rosonina and crew for allowing us to use and modify his fine vessel Kathy Marie, adding considerably to their workload and scheduling problems over the course of the project. Special recognition goes to engineer Tony Melo for solving the many technical issues that this project brought his way.

7. Manuscripts, Presentations and Posters

Manuscripts

Rosenkrantz, G, SM Gallagher, R Shepard, M Blakeslee. 2008. Development of a high-speed, megapixel benthic imaging system for coastal fisheries research in Alaska. Fisheries Research 92(2008)340-344

York, AD, R Taylor, N Vine, S Lerner, S Gallagher. 2008. Using a towed optical habitat mapping system to monitor the invasive *Didemnum vexillum* along the Northeast Continental Shelf. IEEE Oceans08, 10pp.

Taylor, R, NH Vine, AD York, S Lerner, D Hart, J Howland, L Prashad, L Mayer, and SM Gallagher. 2008. Evolution of a Benthic Imaging System From a Towed Camera to an Automated Habitat Characterization System. IEEE Oceans 08. 10 pp.

Presentations and Posters

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Gallager, SM, New Methods for Surveying Sea Scallops, Benthic Organisms and Habitat. Symposium on Optics and Acoustics in Applied Fisheries Oceanography, Bedford Institute of Oceanography, February 2006

Gallager, SM, J Howland, AD York, R Taylor, N Vine, L Prasad, S Swaminarayan, R Gupta P Rago, D Hart, G Rosenkranz, Development of Imaging Hardware and an Optical Image Database and Processing Tools for Automated Classification of Benthic Habitat and Enumeration of Commercially Important Scallop Stocks, 16th International Pectinid Workshop, May 2007.

Howland, J. SM. Gallager, H Singh, A Girard, L Abrams, C Griner. N Vine and R Taylor, Development of a Towed, Ocean Bottom Survey Camera System for Deployment by the Fishing Industry, Oceans '06, Boston September 2006.

York, AD, R Taylor, N Vine, S Lerner, D Hart, L Prashad, and SM Gallager. Development of an Optical Image Database and Processing Tools for Automated Classification of Benthic Habitat and Enumeration of Scallop Stocks, Ocean Biodiversity Symposium, Halifax, NS, Sept 2007.

Gallager, SM, L Mayer, P Auster, R Taylor, N Vine, M Fogarty, and D Hart, The US Northeast Benthic-pelagic Observatory (NEBO) to Support Fisheries and Ecosystem Management, Ocean Biodiversity Symposium, Halifax, Nova Scotia, Sept 2007.

York, AD, R Taylor, N Vine, S Lerner, S Gallager. 2008. Using a towed optical habitat mapping system to monitor the invasive tunicate *Didemnum* sp. along the Northeast Continental Shelf. 2008. National Shellfisheries Association annual meeting.

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9. Selected images

Figure 21. Examples of realtime sonar screen output from various transect areas

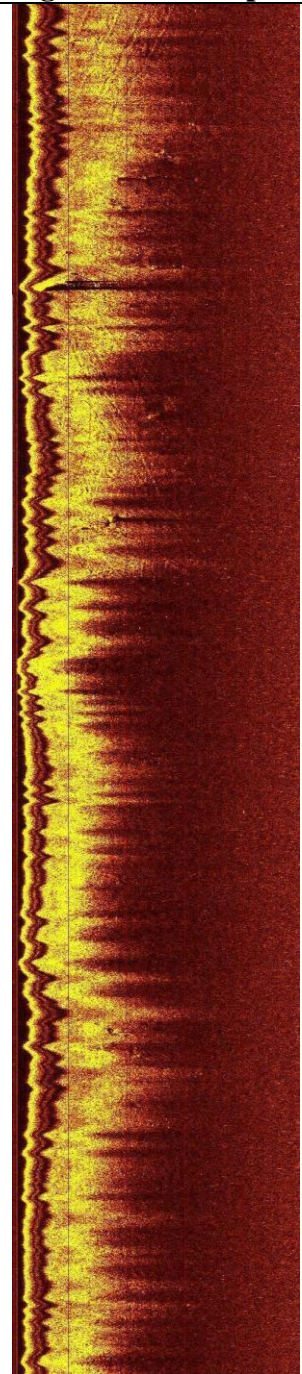
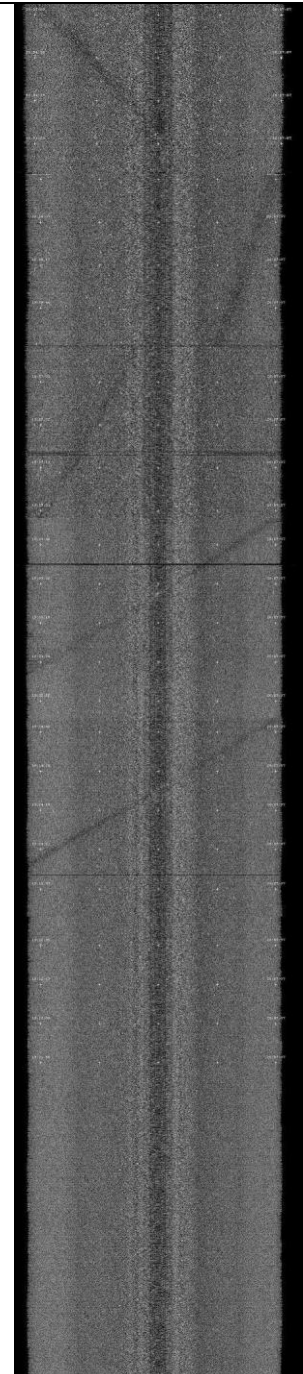
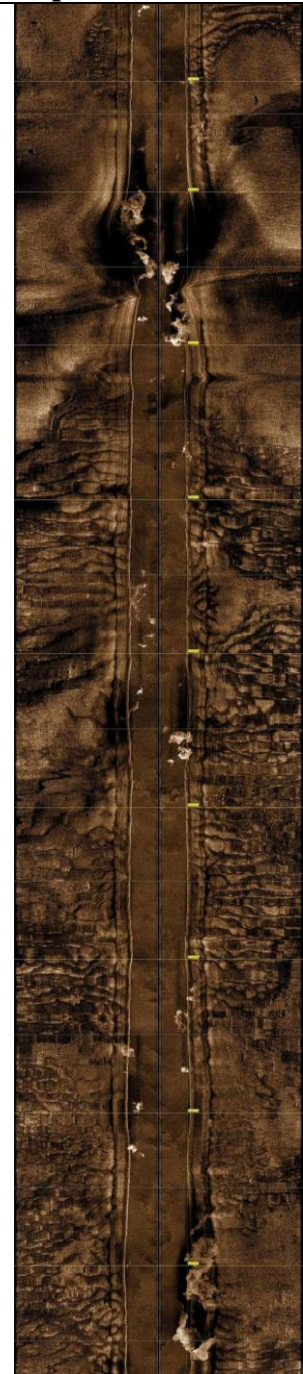
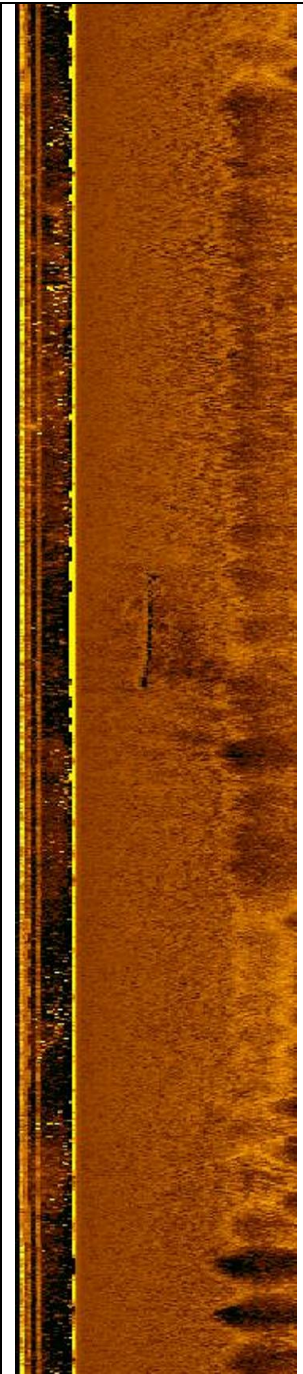
			
<p>21a Trip 1-20070612 Elephant Trunk</p> <p>Imagenix 881a 675 - 1000 kHz on HABCAM vehicle Altitude 3m Image width 50m</p>	<p>21b Trip 2-20070624 Dredge tracks Nantucket Lightship</p> <p>Kongsberg 3002 300 kHz MBES on FOCUS2 vehicle Altitude 50m Image width ~300m</p>	<p>21c Trip 3-20070801 Feed swarms Closed Area 1</p> <p>Applied Signal SAS 175 kHz sidescan on FOCUS2 vehicle Altitude 20m Image width 200m</p>	<p>21d Trip 4-20070926 Wreck 90m length SBNMS</p> <p>BENTHOS C3D 200 kHz MBES Pole mounted Altitude 22m DBT Image width ~60m</p>

Figure 22. Sonar imagery – Imagenix on HABCAM, AST ProSAS on FOCUS2, and pole mount C3D

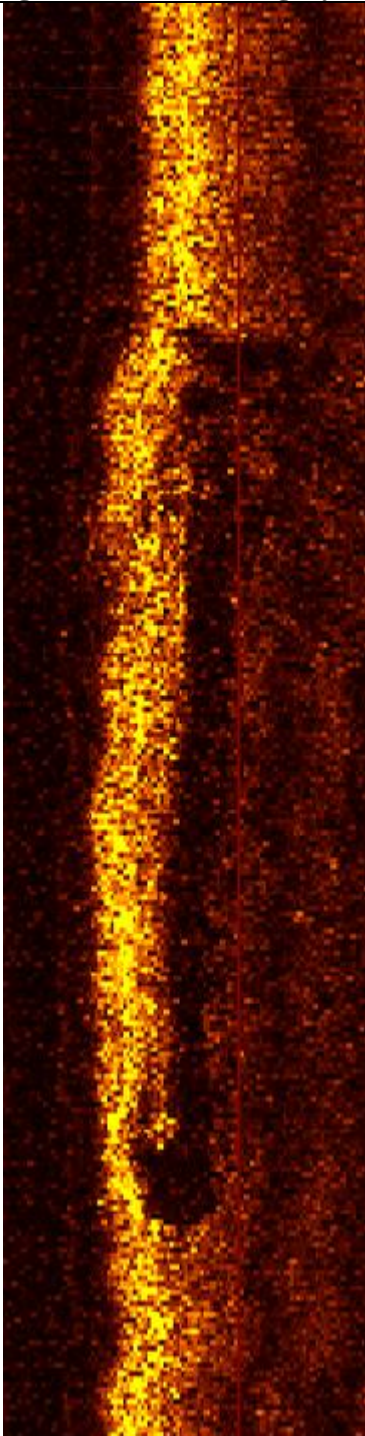
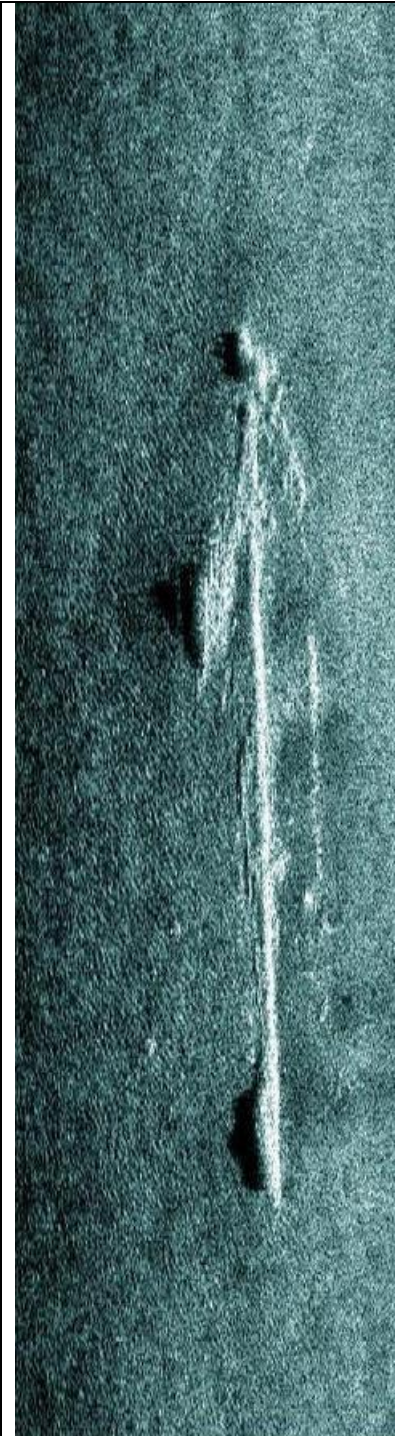

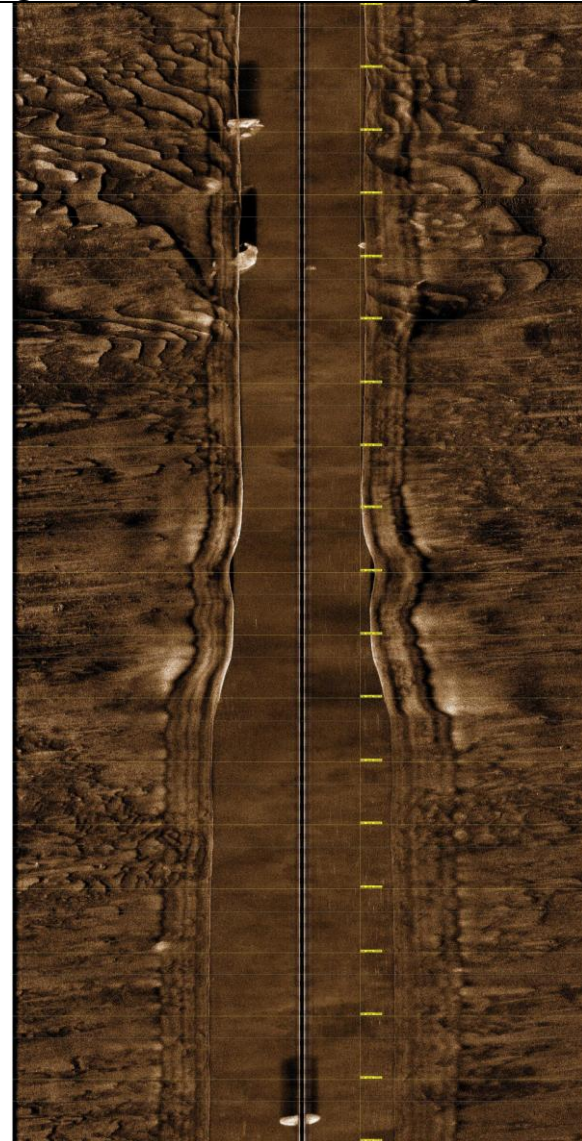
		
<p>Imagenix 675 kHz sisescan mode</p> <p>speed ~4.5 knots altitude ~3 meters FOV ~50 meters</p>	<p>Applied Signal Technology 175 kHz sidescan mode</p> <p>speed ~4.5 knots altitude ~15 meters FOV ~30 meters</p>	<p>BENTHOS C3D 200 kHz multibeam</p> <p>speed ~4.5 knots altitude ~30 m FOV ~30 m</p>

Figure 23. AST transect illustrating acoustic/optical imaging of off bottom “feed” school



Below - full scale feature in center above

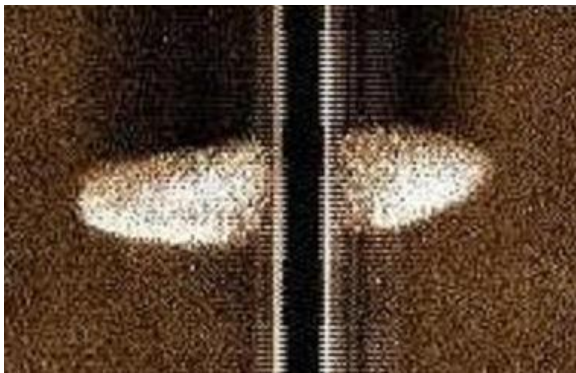


Figure 23a. (top)
AST ProSAS waterfall – 200m total swath
Figure 23b. (bottom)
Amphipod “feed swarm” - width 14 m

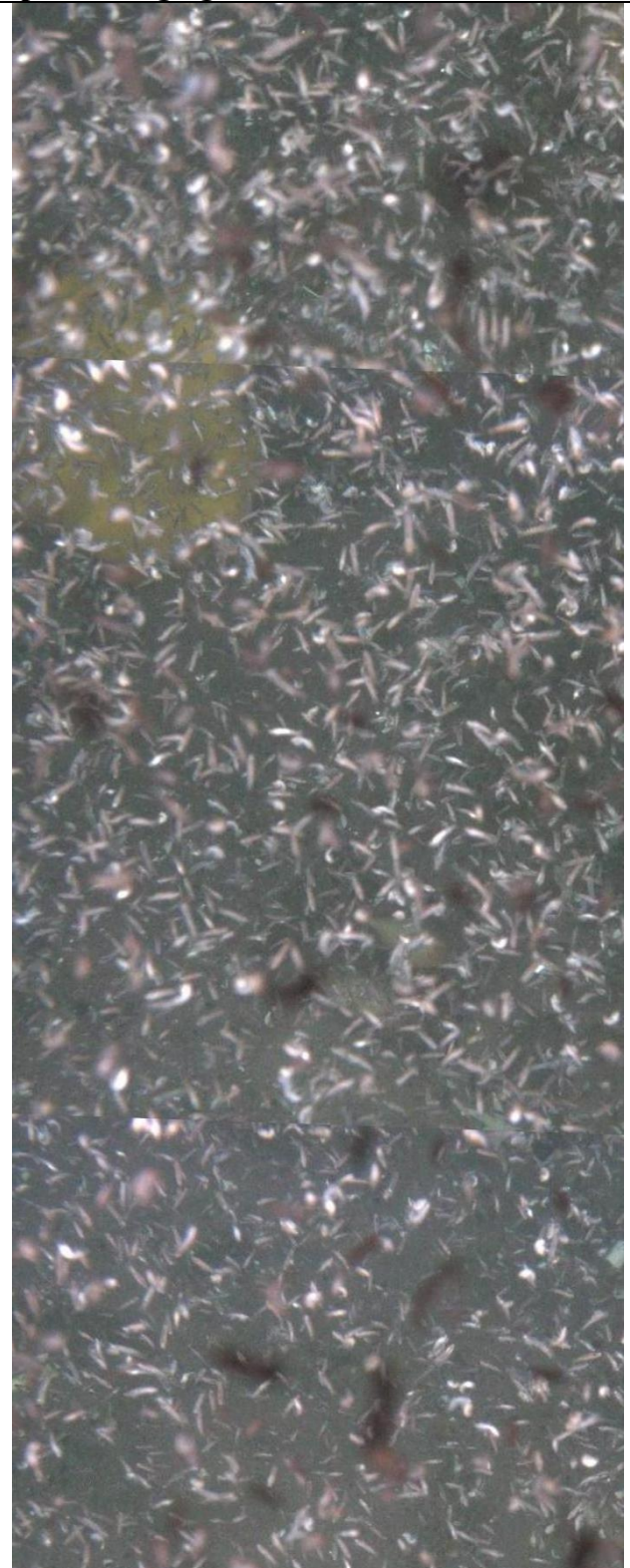


Figure 23c. ~4 meters along track
Amphipods in water column near bottom
Lighting backscatter all but obscures bottom

Figure 24. Optical mosaics from various transect areas, ~length 4 meters
Examples of areas where automated extraction of scallop counts is inherently difficult

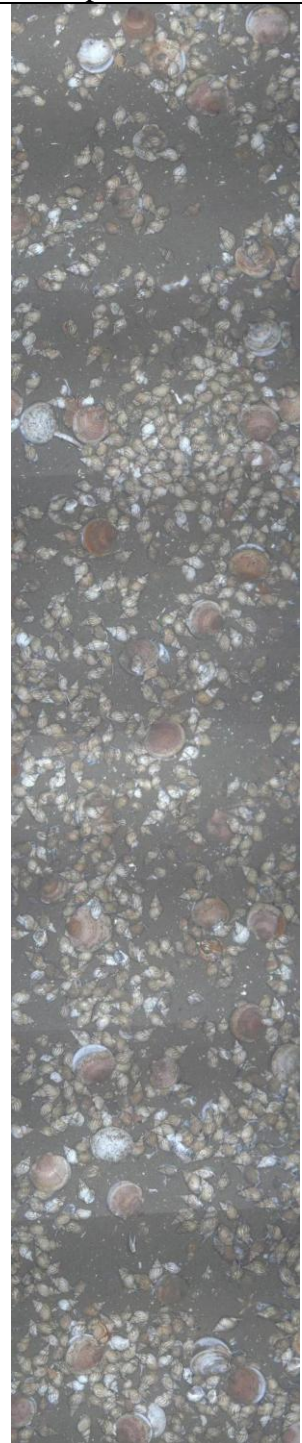


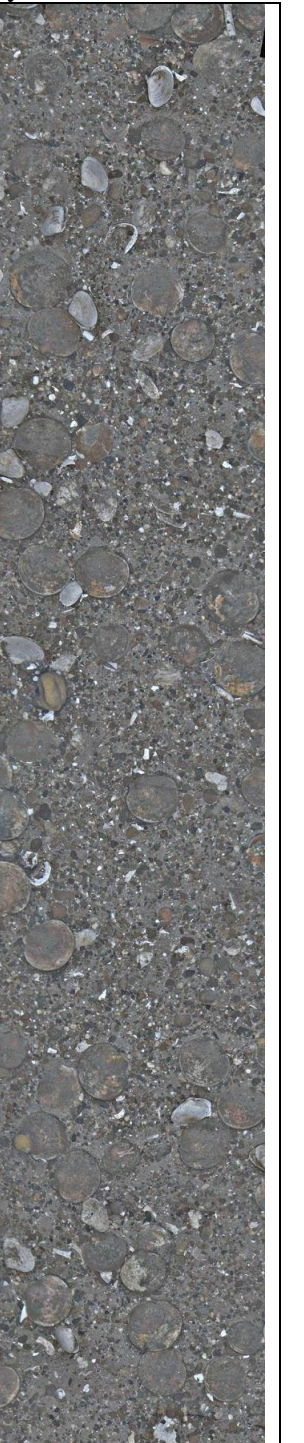
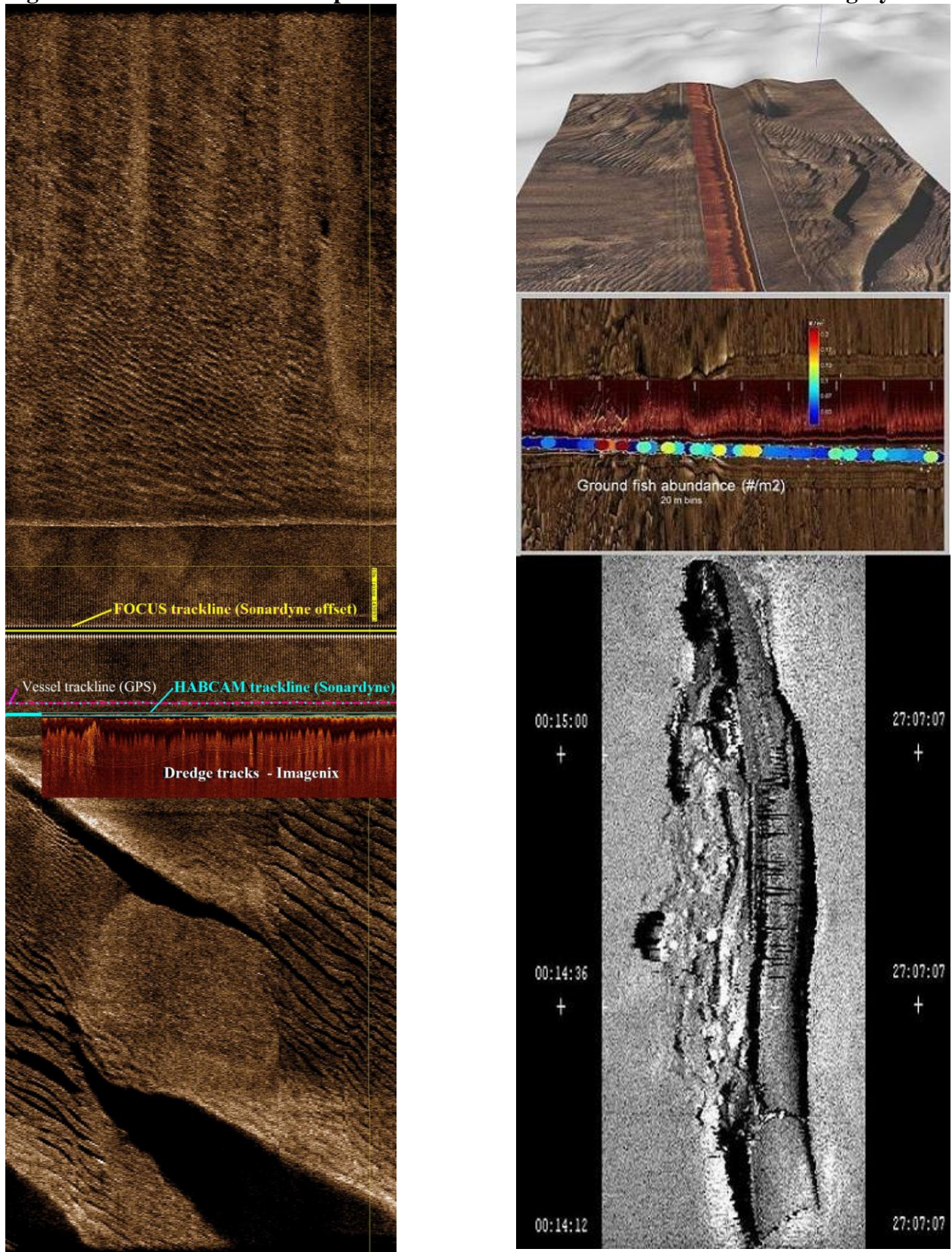
			
24a. Trip 1 - 20070616 Elephant Trunk Carnivorous snails and empty scallop shells	24b. Trip 2 – 20070802 Northern Edge HAPC Invasive tunicate Didemnum on scallops	24c. Trip 2 - 20070803 Northern Edge HAPC Bryozoans on scallops	24d. Trip 2 – 20070804 Northern Edge HAPC Scallops on gravel lag of similar color

Figure 25. Visualization - examples of the AST sidescan and 3002 multibeam imagery



10. Project accounting

A shortfall in funding of ~20% (or ~\$90,000) is noted, brought on by low scallop catch rates and low dockside price during the period of the fund generating trips

Figure 26. Table 5. Final project accounting

BUDGET FINAL RSA 2007		NA07NMF4540030					item	research	Federal	NonFederal	funds	item	note
30 August 2008		Catalog number NA 11-454					subtotal	subtotal	Share	Share	actual	actual	
Form item				no.	rate								
6 a. Personnel	Salaries			0	0		0	0	0	0			
b. Fringe benefits							0	0		0			
c. Travel				5,000	0.44		2,200	2,200		2,200		2,150	
d. Equipment													
	250GB harddrives			42	100		4,200						
	Harddrive cases			10	500		5,000						
	SATA2 PCI cards			4	100		400						
	drive bays and cables			12	50		600						
	Subtotal equipment ----->							10,200		10,200		12,232	
e. Supplies							0					100	
f. Contractual				no.	rate	subt							
	Industry												
#	72,000	CLOSED AREA	4	18,000	7.25	522,000	522,000						
#	174,600	OPEN AREA DAS	100	1,746	7.25	1,265,850	1,265,850						
#	246,600						1,787,850				1,420,021		
	Fishing Vessels				75%		1,340,888		----->	1,340,888	1,065,016		
	Research				25%		446,963				355,005		
	WHOI contract			see attached ----->		206,000						145,466	
	Innerspace Exploration			10	2,000	20,000						20,000	DMF
	Norman Vine			48	500	24,000						21,660	
	Richard Taylor			48	500	24,000						25,220	
	Vessel charter			21	7,000	147,000						60,000	
	Vessel crew											47,452	
	Subtotal research contractual items ----->						421,000	421,000	----->	421,000		319,798	
g. Construction							0	0		0			
h. Other				no.	rate	months							
	Additional Insurance			21	300		6,300						
	Communications	website		2	50	12	1,200						
		telephone		2	50	12	1,200						
	Printing						363						
	Meetings			500	9		4,500						
	Subtotal Other ----->							13,563	----->	13,563		20,725	
	Subtotal noncontract research items ---->							25,963				35,207	
	Subtotal contractual research items ---->							421,000				319,798	
	Total research related budget-->							446,963				355,005	
i. Total direct charges										1,787,851			
j. Indirect charges										0			
k. TOTAL PROJECT BUDGET	----->							0		1,787,851			
7 Program income										0		0	